

COTTON

Predicting Cotton Boll Maturation Period Using Degree Days and Other Climatic Factors

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ABSTRACT

Degree days are often used for cotton (*Gossypium hirsutum* L.) growth monitoring and management. The objectives of this research are to determine if 15.5°C is an accurate lower-threshold temperature to monitor the boll maturation period (BMAP) for cotton in the northern, rainfed region of the U.S. Cotton Belt, to investigate other climatic factors in this cotton region that may improve the accuracy of the current degree day system for cotton, and to evaluate degree day models that include both an upper- and lower-threshold temperature. Cotton was planted at three different timings in 2001 and 2002 to provide different climatic regimes during the BMAP. On 10 typical plants per plot, all first-position flowers were individually tagged with date of flower opening and were then harvested at full maturity. Daily weather data consisted of maximum, minimum, and average air temperature; maximum and average soil temperature; average soil moisture; maximum and average solar radiation; and maximum and average photosynthetically active radiation. The 17°C degree day model, which used 17°C as the lower threshold, provided the best adjusted r^2 (0.2715) of all the single-variable models; the degree day 15.5°C model had an adjusted r^2 of 0.2276. The best model using both upper and lower temperature thresholds was DD3017, using 30 and 17°C as the thresholds, and had an adjusted r^2 of 0.2452. Adding average, minimum, and maximum air temperatures to the DD15.5, DD17, and DD3017 models reduced coefficient of variation and mean square error and increased adjusted r^2 values.

DEGREE DAY MODELS are a common method to monitor crop progress and predict phenology of crops such as maize [*Zea mays* L.], soybean [*Glycine max* (L.) Merr.], sorghum [*Sorghum bicolor* (L.) Moench], and cotton (Andrade et al., 2000; Cober et al., 2001; Reddy et al., 1992; Staggenborg et al., 1999). Accurate models for temperature effects are valuable to physiologists, modelers, breeders, and crop producers (Andrade et al., 2000). Degree days can be used for predicting crop development to aid in variety selection; insect, disease, and weed control scheduling; and timing of irrigation, defoliation, and harvest (Idso et al., 1978; Larson et al., 2002; Logan and Gwathmey, 2002; Mi et al., 1998; Wanjura et al., 2002).

A model is considered accurate if meaningful biological thresholds are determined by research (Baskerville and Emin, 1969). Much work has been conducted on

degree days during cotton BMAP, which is defined as the number of days from open bloom to open boll (Gipson and Joham, 1968). Boll maturation period has been shown to increase with the advance of the growing season because of the gradual reduction of temperature during the season (Anderson and Kerr, 1938; Hawkins and Servis, 1930). Gipson and Joham (1968) reported that mean night temperature was more influential on BMAP than mean day temperature as mean night temperatures in this study were considerably lower than mean day temperatures. For night temperatures ranging from 5 to 25°C, BMAP was increased by 3.4 d per degree decrease in mean temperature (Gipson and Joham, 1968). Conversely, Yfoulis and Fasoulas (1973, 1978) reported that both day and night temperatures are highly influential on BMAP. Reddy et al. (1997) reported that BMAP was reduced by 6.9 d per degree of increased mean temperature from 21.5 to 30.5°C.

Although, mean temperatures influence BMAP, the limiting factor for boll development in many growing areas is the minima and maxima, not necessarily the mean temperature (Liakatas et al., 1998; Yfoulis and Fasoulas, 1973). Research has indicated that optimal boll development occurs when maximum temperatures are below 30°C (Lomas et al., 1977) and when minimum temperatures are above 12°C (Roussopoulos et al., 1998). On the other hand, Yfoulis and Fasoulis (1978) reported that the maximum and minimum thresholds were 30.5 to 32°C and 15 to 16.5°C and that the specific minima and maxima temperatures depended on genotype. Other research also reported genotype differences in boll development in response to temperature (Gipson and Ray, 1970). Roussopoulos et al. (1998) reported that within the temperature range from 16 to 35°C, a degree change in the minima or maxima temperature can decrease or increase BMAP by 14 d.

In the currently accepted model for cotton degree day accumulation, degree days are calculated directly from the difference between the daily mean temperature and a lower threshold that represents the lower limit for growth of the crop in question (Arnold, 1960; Baskerville and Emin, 1969; Wang, 1960). More complex models utilize both an upper and lower temperature threshold.

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Abbreviations: AAT, average air temperature; APAR, average photosynthetically active radiation; ASM, average soil moisture; AST, average soil temperature; ASUN, average solar radiation; BMAP, boll maturation period; CV, coefficient of variation; DDx, degree days calculated with base x°C; MNAT, minimum air temperature; MSE, mean square error; MXAT, maximum air temperature; MXPAR, maximum photosynthetically active radiation; MXST, maximum soil temperature.

Some researchers report that precision is not increased with the introduction of the additional upper threshold (Baskerville and Emin, 1969). Researchers in the western Cotton Belt use a 30/13°C threshold to increase precision because this region has extreme minima and maxima temperatures compared with more temperate cotton areas (Unruh and Silvertooth, 1997). However, Arnold (1960) found a 2 to 4% error for both types of models because of the difference between calculated degree days and the actual degree days.

Preliminary research in North Carolina indicated a disjunction between cotton development rate and accumulated degree days, possibly attributed to an improper lower-threshold temperature of 15.5°C for degree day calculations. This research was initiated to determine if the current cotton degree day model could be improved by modifying temperature threshold(s) and/or by including climatic factors other than thermal indices. The objectives of this research were to determine if 15.5°C is an accurate lower-threshold temperature to monitor the BMAP for cotton in the northern, rainfed region of the U.S. Cotton Belt; to investigate other climatic factors in this cotton region that may improve the accuracy of the current degree day system for cotton; and to evaluate degree day models that include both an upper- and lower-threshold temperature.

MATERIALS AND METHODS

Experimental Design

Experiments were conducted in 2001 and 2002 at the Central Crops Research Station near Clayton, NC (35°39' N, 78°28' W), on a Dothan sandy loam (fine-loamy, siliceous, thermic, plinthic Paleudults). Seed (cv. Delta and Pine Land 458 Bollgard/Roundup Ready) was planted with a John Deere Max Emerge vacuum planter on raised beds 0.97 m wide; final populations were 111 000 and 104 000 plants ha⁻¹ in 2001 and 2002 for all planting dates, respectively. Planting dates in 2001 were 9 May, 31 May, and 14 June; 2002 planting dates were 2 May, 23 May, and 14 June. Tillage was only conducted during the preplanting period. Fertilization, weed control, insect control, and plant growth regulation decisions were conducted according to North Carolina Extension recommendations uniquely for each planting date (Bachelier, 2003; Crozier, 2003; Edmisten, 2003; York and Culpepper, 2003). Plots consisted of four rows 12.2 m long; treatments were replicated four times in a randomized, complete block design.

Sampling

Weather data was collected from a State Climate Office of North Carolina weather station located 1.3 km from the experiment site and consisted of maximum air temperature (MXAT), minimum air temperature (MNAT), average air temperature (AAT), maximum soil temperature (MXST), average soil temperature (AST), average soil moisture (ASM), average solar radiation (ASUN), maximum photosynthetically active radiation (MXPAR), and average photosynthetically active radiation (APAR).

At first flower, 10 typical plants per plot were flagged for subsequent flower tagging (120 plants total per test). On flagged plants only, all first-position flowers were tagged every other day with the Julian date noted. White flowers were tagged with the current day's date while pink flowers were tagged

with the previous day's date. Tagging continued every other day until the last first-position white or pink flower was tagged. Tagged bolls were individually harvested when all carpels cracked and lint was first visible, an indicator of full maturity (Oosterhuis and Jernstedt, 1999). Boll maturation period was calculated for each individual boll as the number of days between the initial tagging of a flower and cracked boll harvest. Tagging data and weather data were merged such that each individual boll had weather data for its associated BMAP. Degree day (DD) values were calculated as described in Baskerville and Emin (1969) as:

$$DD\ L = \Sigma[(T_x + T_n)/2 - L]$$

where T_x is the daily maximum, T_n is the daily MNAT, and L is the low temperature threshold. Additionally, alternative degree day models including both an upper and lower temperature threshold were calculated as described by Unruh and Silvertooth (1997) as:

$$DD\ H/L = \Sigma[(T_x + T_n)/2 - L]$$

where T_x is the daily maximum that cannot exceed the upper threshold H , T_n is the daily MNAT, and L is the low temperature threshold.

Regression Analysis

Data were first analyzed with PROC GLM in SAS using specified error terms to determine if the 2 yr of data could be combined. Year \times treatment interaction was not significant, so data were pooled over years. Data were then analyzed with PROC REG as a stepwise regression procedure using the selection option based on adjusted r^2 , mean square error (MSE), and coefficient of variation (CV) to determine the best model. Stepwise regression with forward selection builds a model by successively adding a term using the most significant remaining variable based on specific selection options such as adjusted r^2 and MSE (Moog and Whiting, 2002). All possible multiple-variable models were analyzed, but only those that greatly improved the models are included in the results. Residual plots were developed using PROC PLOT to determine homogeneity of variance. Principal factor analysis was also conducted using PROC FACTOR in an effort to produce a minimum number of principal components to represent the maximum portion of variance from the data collected. Simple linear correlations were initially calculated to determine significant interrelationships between all the weather variables. Due to differences in measurement units, the analysis was conducted on the correlation matrix (Brejda, 1998). Furthermore, factors were subjected to varimax rotation to redistribute the variance of each variable so that each variable loads mainly on one factor (Sharma, 1996). Factor analysis, though, did not simplify the models with climatic factors, so this analysis was not used.

RESULTS

Each boll had an associated weather data set for its BMAP; the data in Table 1 are an average of these weather data sets for each planting date. During both years, DD3013 (degree days calculated with base 30/13°C), DD15.5, MXAT, MNAT, AAT, MXST, AST, ASUN, and MXPAR values declined with each corresponding later date of planting. All parameter means, except those for ASM and APAR, were significantly different among the different planting dates within the same year.

Of the degree day models with only a lower threshold, the DD17 model proved slightly better than other mod-

Table 1. Degree day 15.5 (DD15.5) and 30/13 (DD3013); maximum (MXAT), minimum (MNAT), and average (AAT) air temperature; maximum (MXST) and average (AST) soil temperature; average soil moisture (ASM); average solar radiation (ASUN); maximum (MXPAR) and average (APAR) photosynthetically active radiation during boll maturation period for each planting date in 2001 and 2002 at Clayton, NC.

Year	Planting date	DD15.5	DD3013	MXAT	MNAT	AAT	MXST	AST	ASM	ASUN	MXPAR	APAR
		— degree days —				°C			m ³ m ⁻³	W m ⁻²	— mol m ⁻² d ⁻¹ —	
2001	9 May†	459a‡	579a	27.6a	17.2a	22.0a	27.7a	24.6a	0.39a	206.7a	105.2a	23.1a
2001	31 May	383b	521b	26.7b	15.1b	20.4b	25.5b	23.4b	0.39a	202.8b	103.9b	23.1a
2001	14 June	289c	421c	25.2c	12.9c	18.6c	23.4c	22.1c	0.39a	192.3c	101.1c	22.6a
2002	2 May	541A	624A	30.5A	20.0A	25.1A	29.7A	27.4A	0.33A	209.2A	152.3A	35.9A
2002	23 May	496B	607B	28.5B	18.7B	23.1B	27.8B	25.6B	0.35B	176.3B	136.1B	29.2B
2002	14 June	472C	596B	26.9C	17.8C	21.8C	26.3C	24.3C	0.38C	156.6C	127.1C	25.5C

† Calculated as the average of the individual weather data sets for each boll collected within a planting date.

‡ Means within a column followed by the same lowercase letter are not significantly different for 2001 data while data within a column followed by the same uppercase letter are not statistically different for 2002 data using Fisher's protected LSD at $\alpha = 0.05$.

els with an adjusted r^2 of 0.2715 compared with 0.2468, 0.2276, 0.1654, 0.1200, 0.1188, 0.0919, 0.0813, and 0.0564 for the DD16, DD15.5, DD14, DD16.5, DD13, DD15, DD14.5, and DD13.5 models, respectively (Table 2). Adjustments to the current DD15.5 model by including other variables increased its accuracy in predicting the time period required for boll maturation (Table 3). All climatic factors except soil moisture significantly affected the BMAP ($p < 0.01$). Of the single variable models constructed relating BMAP to DD15.5 and all climatic factors, the DD15.5 provided the best description, with an adjusted r^2 of 0.2276. The AST, MXPAR, APAR, ASM, MXAT, ASUN, AAT, MNAT, and MXAT models all had lower adjusted r^2 of 0.1088, 0.0906, 0.0686, 0.0473, 0.0188, 0.0163, 0.0079, 0.0033, and 0.0001, respectively. The relatively higher r^2 of the DD15.5 model agrees with previous research, which indicated that development rate is primarily dictated by degree days (Burke et al., 1988).

All weather variables were analyzed for multiple regression models, but only those that greatly improved accuracy are presented here. The addition of AAT improved both the DD15.5 and the alternative DD17 models by increasing their respective adjusted r^2 values to 0.2727 and 0.3293 and decreasing MSEs and coefficient of variances (Table 3). Moreover, a three-variable model consisting of DD15.5, MNAT, and MXAT increased the adjusted r^2 to 0.3615 and slightly reduced MSE to 6.41 and CV to 11.49. The DD17/MNAT/MXAT model

proved to be the best of the DD15.5 alternative models with an adjusted r^2 , MSE, and CV of 0.3917, 2.27, and 10.49, respectively. Addition of more variables to this model did not increase the accuracy or reduce MSE or CV (data not shown).

Degree day models with both an upper and lower temperature threshold were a slight improvement over the currently used single-threshold DD15.5 model (Table 4). Models consisting of DD3017 (degree days calculated with base 30/17°C), DD3016 (degree days calculated with base 30/16°C), DD3014 (degree days calculated with base 30/14°C), DD3013 (degree days calculated with base 30/13°C), and DD3015.5 (degree days calculated with base 30/15.5°C) had adjusted r^2 values of 0.2452, 0.2008, 0.1075, 0.0595, and 0.0407, respectively, compared with 0.2276 for the DD15.5 model. Similar to models with only the lower threshold, the addition of AAT, MNAT, and MXAT improved these dual-threshold models. The DD3017/AAT and the DD3017/MNAT/MXAT models had greater accuracy and lower error than the DD3017 model. Using more climatic factors in the model slightly improved the model (data not shown). These three climatic factors (AAT, MNAT, and MXAT) could be useful tools to adjust for temperature effects on boll maturation just as photothermal quotients and thermal indices have improved the relationship of temperature on maize development (Andrade et al., 2000; Stewart et al., 1998).

Of all models used in this study, the DD17/MNAT/MXAT was the superior model with an adjusted r^2 , MSE, and CV of 0.3917, 2.27, and 10.49, respectively compared with 0.2276, 7.06, and 11.84 for the DD15.5 model (Table 5). The best two-variable model was the DD17/AAT model with an adjusted r^2 of 0.3293, MSE of 6.57, and CV of 11.02. The DD17 model was the superior single-variable model but only slightly better than the DD3017 model.

DISCUSSION

Degree day variables were negatively correlated with BMAP, which is similar to research that indicated both boll size and maturation period decreased as temperature increased in a growth chamber setting (Reddy et al., 1999). Degree days with base 17°C proved to be a more accurate lower threshold than the DD15.5 model. This finding contradicts our hypothesis that a lower

Table 2. Degree day 15.5 model modifications: single-variable regression equations, adjusted r^2 values, mean square error (MSE), and coefficient of variation (CV) describing cotton boll maturation period (Y) based on different degree day models. All models include 608 data points and are listed in decreasing order of accuracy.

Equations†	a	b	Adjusted r^2	MSE	CV
Y = DD17a + b	-0.0582**	82.69**	0.2715	6.86	11.50
Y = DD16a + b	-0.0581**	86.97**	0.2468	6.97	11.69
Y = DD15.5a + b	-0.0509**	83.58**	0.2276	7.06	11.84
Y = DD14a + b	-0.0428**	83.51**	0.1654	7.34	12.31
Y = DD16.5a + b	-0.0530**	83.23**	0.1200	7.54	12.62
Y = DD13a + b	-0.0366**	82.13**	0.1188	7.54	12.64
Y = DD15a + b	-0.0504**	87.55**	0.0919	7.66	12.82
Y = DD14.5a + b	-0.0474**	87.22**	0.0813	7.70	12.90
Y = DD13.5a + b	-0.0400**	85.23**	0.0564	7.80	13.07

** Significant at the 0.01 level.

† Y, boll maturation period; DD17, degree day 17; DD16, degree day 16; DD15.5, degree day 15.5; DD14, degree day 14; DD16.5, degree day 16.5; DD13, degree day 13; DD15, degree day 15; DD14.5, degree day 14.5; DD13.5, degree day 13.5.

Table 3. Degree day 15.5 model modifications: Regression equations, adjusted r^2 values, mean square error (MSE), and coefficient of variation (CV) describing cotton boll maturation period (Y) based on various degree day models with other climatic factors. All models include 608 data points and are listed in decreasing order of accuracy.

Equations†	a	b	c	d	Adjusted r^2	MSE	CV
$Y = DD17a + MNATc + MXATd + b$	-0.0433**	114.83**	-1.2098**	-0.5902**	0.3917	2.27	10.49
$Y = DD15.5a + MNATc + MXATd + b$	-0.0359**	116.83**	-1.2785**	-0.5295**	0.3615	6.41	11.49
$Y = DD17a + AATc + b$	-0.0771**	92.22**	-0.0043**		0.3293	6.57	11.02
$Y = DD15.5a + AATc + b$	-0.0666**	93.00**	-0.0004**		0.2727	6.85	11.49
$Y = DD15.5a + b$	-0.05090**	83.58**			0.2276	7.06	11.84
$Y = ASTa + b$	0.00044**	56.84**			0.1088	7.58	12.71
$Y = MXPARa + b$	0.00018**	57.23**			0.0906	7.66	12.84
$Y = APARa + b$	0.00031**	58.11**			0.0686	7.75	12.30
$Y = ASMa + b$	0.00039	58.9			0.0473	7.84	13.14
$Y = MXATa + b$	-0.02827**	60.77**			0.0188	7.98	13.33
$Y = ASUNa + b$	0.00006**	58.82**			0.0163	7.96	13.58
$Y = AATa + b$	0.00014**	58.99**			0.0079	8.00	13.41
$Y = MNATa + b$	0.03472**	59.15**			0.0033	8.02	13.44
$Y = MXSTa + b$	-0.00001**	59.67**			0.0001	8.03	13.47

** Significant at the 0.01 level.

† Y, boll maturation period; DD17, degree day 17; MNAT, minimum air temperature; MXAT, maximum air temperature; DD15.5, degree day 15.5; AAT, average air temperature; AST, average soil temperature; MXPAR, maximum photosynthetically active radiation; APAR, average photosynthetically active radiation; ASM, average soil moisture; MXAT, maximum air temperature; ASUN, average solar radiation; AAT, average air temperature; MNAT, minimum air temperature; MXST, maximum soil temperature.

threshold was needed in the northern, rainfed region of the U.S. Cotton Belt. These results, though, do agree with previous research that indicated temperatures above 15 to 16.5 were optimal for boll maturation (Yfoulis and Fasoulis, 1978). Another interesting result of this study was that degree days with base 17, 16, 15.5, and 14°C had higher r^2 values than the model with base 16.5°C. This may be due to experimental error. Another possible explanation is that at 16.5°C, some biochemical factor becomes limiting. Research on photosynthesis has shown that a photochemical limitation can occur at certain temperature regimes due to the temperature sensitivity of a rate limiting enzyme (McWilliam and Naylor, 1967).

The degree day baseline temperature of 15.5°C for cotton is based on a very large pool of research that studied temperature effects on different growth stages (Mauney, 1986) such as field emergence (Anderson, 1971), vegetative development and fruiting (Young et al., 1980), and first bloom (Bilbro, 1975). The fact that the original baseline temperature was derived from a pool of data that dealt with other phenological stages besides boll maturation may be why 17°C proved to be a better baseline temperature than 15.5°C is our study, which just focused on boll maturation.

Adding AAT, MNAT, and MXAT to the DD15.5, DD17, and DD3017 models reduced CV and MSE and increased adjusted r^2 in this experiment. This study

agrees with previous research in that all biological variation cannot be explained solely by degree day accumulation data (Idso et al., 1978). Similar modifications with maize models have been shown to reduce CV, which is an indicator of the reliability of the model when looking at different planting dates and different years (Stewart et al., 1998).

Most research conducted on temperature effects on cotton development indicated an upper threshold of 30°C. Gross photosynthesis increased linearly when the ambient air temperature increased to 30°C and declined at 40°C (Hodges, 1991). Optimal temperatures for vegetative and reproductive growth were 30/22°C when cotton was grown at 20/12, 25/17, 30/22, 35/27, and 40/32°C. Temperatures above certain limits causes a lower ratio of assimilates to respiration and less translocation of photosynthates (Yfoulis and Fasoulas, 1978). Thus, an upper threshold for degree day calculation would seem appropriate, but this study demonstrated that the DD3017 model did not improve accuracy compared with the DD17 model. One possible reason is that the 30°C is not an appropriate upper threshold. Yfoulis and Fasoulas (1973) indicated temperatures up to 32°C decreased BMAP, but the limit and level of BMAP change was largely influenced by genotype. A dual-threshold model has been used successfully in other crops such as maize because this type of model accounts for the decreasing rate of development as air temperature ex-

Table 4. Degree day 30/13 model modifications: regression equations, adjusted r^2 values, mean square error (MSE), and coefficient of variation (CV) describing cotton boll maturation period (Y) based on various degree day models and other climatic factors. All models include 608 data points and are listed in decreasing order of accuracy.

Equations†	a	b	c	d	Adjusted R^2	MSE	CV
$Y = DD3017a + MNATc + MXATd + b$	-0.0516**	117.52**	-1.2535**	-0.5188**	0.3732	6.47	10.66
$Y = DD3017a + AATc + b$	-0.0874**	92.47**	-0.0003**		0.2779	6.82	11.44
$Y = DD3017a + b$	-0.0714**	85.24**			0.2452	6.98	11.70
$Y = DD3016a + b$	-0.0623**	85.39**			0.2008	7.18	12.04
$Y = DD3014a + b$	-0.0442**	82.84**			0.1075	7.59	12.72
$Y = DD3013a + b$	-0.0331**	78.90**			0.0595	7.79	13.06
$Y = DD3015.5a + b$	-0.0459**	82.77**			0.0407	7.87	13.18

** Significant at the 0.01 level.

† Y, boll maturation period; DD3017, degree day 30/17; MNAT, minimum air temperature; MXAT, maximum air temperature; AAT, average air temperature; DD3016, degree day 30/16; DD3014, degree day 30/14; DD3013, degree day 30/13; DD3015.5, degree day 30/15.5.

Table 5. Comparison of best models from single-variable models, modifications of the DD15.5 model, and modifications to the 30/13 model: regression equations, adjusted r^2 values, mean square error (MSE), and coefficient of variation (CV) describing cotton boll maturation period (Y) based on degree day models and other climatic factors. All models include 608 data points and are listed in decreasing order of accuracy.

Equations†	a	b	c	d	Adjusted r^2	MSE	CV
$Y = DD17a + MNATc + MXATd + b$	-0.0433**	114.83**	-1.2098**	-0.5902**	0.3917	2.27	10.49
$Y = DD3017a + MNATc + MXATd + b$	-0.0516**	117.52**	-1.2535**	-0.5188**	0.3732	6.47	10.66
$Y = DD17a + AATc + b$	-0.0771**	92.22**	-0.0043**		0.3293	6.57	11.02
$Y = DD3017a + AATc + b$	-0.0874**	92.47**	-0.0003**		0.2779	6.82	11.44
$Y = DD17a + b$	-0.0582**	82.69**			0.2715	6.86	11.50
$Y = DD3017a + b$	-0.0714**	85.24**			0.2452	6.98	11.70
$Y = DD15.5a + b$	-0.0509**	83.58**			0.2276	7.06	11.84

** Significant at the 0.01 level.

† Y, boll maturation period; DD17, degree day 17; MNAT, minimum air temperature; MXAT, maximum air temperature; DD3017, degree day 30/17; AAT, average air temperature; DD15.5, degree day 15.5.

ceeds the optimum range (Coligado and Brown, 1975). Furthermore, a dual-threshold model indirectly accounts for diurnal temperature fluctuations because these fluctuations do affect boll development (Thaker et al., 1989).

To conclude, this research indicates that alternative models, such as the DD17 or DD17/MNAT/MXAT, slightly improve the model for BMAP but may increase the complexity of calculations. Simplicity of the current degree day calculations is the primary reason for its widespread adoption (Stewart et al., 1998). Additional research under various conditions is needed to determine if these complex models are more accurate than the current widely accepted DD15.5 model in monitoring of BMAP in cotton in the northern, rainfed region of the U.S. Cotton Belt.

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